

Docket No.: SL-109

Harrington & Smith, LLP Docket No.: 907.0120.U1(US)

Patent Application Papers of: Merle L. Keller, Vaughn L.
Mower, Kent R. Bruening

System and Method for Generating and Acquiring Pseudo-Noise
(PN) Spread Signals

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
221

System and Method for Generating and Acquiring Pseudo-
Noise (PN) Spread Signals

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to spread spectrum communication systems using PN coding techniques and, more particularly, to acquiring PN code phase.

2. Prior Art

Spread spectrum (SS) systems, which may be CDMA systems, are well known in the art. SS systems can employ a transmission technique in which a pseudo-noise (PN) PN-code is used as a modulating waveform to spread the signal energy over a bandwidth much greater than the signal information bandwidth. At the receiver the signal is de-spread using a synchronized replica of the PN-code.

In general, there are two basic types of SS systems: direct sequence spread spectrum systems (DSSS) and frequency hop spread spectrum systems (FHSS).

The DSSS systems spread the signal over a bandwidth $f_{RF} \pm R_c$, where f_{RF} represents the carrier frequency and R_c represents the PN-code maximum chip rate, which in turn may be an integer multiple of the symbol rate R_s . Multiple access systems employ DSSS techniques when transmitting multiple channels over the same frequency bandwidth to multiple receivers, each receiver sharing a common PN code or having its own designated PN-code. Although each receiver receives the entire frequency bandwidth, only

the signal with the receiver's matching PN-code will appear intelligible; the rest appears as noise that is easily filtered. These systems are well known in the art and will not be discussed further.

- 5 FHSS systems employ a PN-code sequence generated at the modulator that is used in conjunction with an m-ary frequency shift keying (FSK) modulation to shift the carrier frequency f_{RF} at a hopping rate R_h . A FHSS system divides the available bandwidth into N channels and hops
- 10 between these channels according to the PN-code sequence. At each frequency hop time a PN generator feeds a frequency synthesizer a sequence of n chips that dictates one of 2^n frequency positions. The receiver follows the same frequency hop pattern. FHSS systems are also well
- 15 known in the art and need not be discussed further.

- As noted, the DSSS system PN-code sequence spreads the data signal over the available bandwidth such that the signal appears to be noise-like and random; but the signal is deterministic to a receiver applying the same
- 20 PN-code to de-spread the signal. However, the receiver must also apply the same PN-code at the appropriate phase in order to de-spread the incoming signal, which explicitly implies synchronization between the receiver and transmitter. However, in group communication
- 25 environments, such as a fleet battle-group where the battle-group composition changes regularly (daily or even hourly); or where the participants are engaged in a common training exercise, but geographically dispersed around the globe, typical synchronization techniques,
- 30 such as resetting the start of the PN code for all the participants, is not practical. Moreover, communication interruptions due to resetting PN codes at an arbitrary

time seam, such as days, weeks, months, and years, in a battle-group environment could have undesirable consequences. As used herein, a time seam occurs when a fleet of platforms begins its PN code from the beginning of a time event, such as the Global Positioning System (GPS) day in which the fleet assembles. The convention used by the fleet is to ignore subsequent GPS day boundaries once communication among the fleet has begun, meaning that the PN code shared among the fleet is not reset at subsequent GPS day boundaries.

In this manner, fleet communications can persist for two or three days. However, a platform that attempts to join the fleet and participate in fleet communications, subsequent to the beginning of the time event is confronted with a time and PN code phase ambiguity and will be unable to join fleet communications.

Some systems may use three-component PN codes where acquisition is often achieved by searching each component code for phase alignment with the PN-encoded signal one chip at a time. This means that each chip of a component code must be searched in order to discover its phase alignment with the PN code. Although a common practice with many three-component codes, this brute force approach is time consuming. In addition, this approach is impractical with MANDED or certain combinations of four-subcomponent (x, y, z_1, z_2) PN codes, discussed herein, since the number of chips is $x + y + (z_1 \times z_2)$ as opposed to a logic xor combination such as $x + y + z_1 + z_2$. Thus, a brute force, chip-by-chip acquisition approach becomes prohibitive because of the very large number of chips to search.

It is therefore desirable to provide a method and system whereby platforms (communication systems) may join fleet communications at any time with unambiguous time and PN code phase alignment.

5

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome, and other advantages are realized, in accordance with the presently preferred embodiments of these teachings.

- 10 In accordance with one embodiment of the present invention, a system for generating and acquiring pseudo-noise (PN) spread signals is provided. The system includes a transmitter, having a first clock and at least three first pseudo-noise (PN) component code generators
- 15 coupled to the first clock. The transmitter also includes a logic combiner coupled to the PN component code generators and is adapted to generate a composite PN code. A second clock is mathematically slaved with the first clock while both clocks are coupled to respective
- 20 N-bit counters. The system also includes a receiver adapted to receive partially correlated signals from the transmitter, and includes a link control processor and a modulator/demodulator controller coupled to the link control processor. The receiver also includes a first
- 25 receiver clock and at least three first receiver pseudo-noise (PN) component code generators coupled to the first receiver clock. In addition, the receiver includes a despreader coupled to one of the receiver PN component code generators and a receiver logic combiner coupled to
- 30 the receiver PN component code generators. The receiver

logic combiner is adapted to generate the composite PN code. A second receiver clock is adapted to synchronize with the receiver first clock and both are coupled to N- and P-bit counters, respectively.

- 5 In accordance with another embodiment of the invention, a method for generating and acquiring pseudo-noise (PN) composite spread signals is provided. The method includes the steps of providing a PN clock source having a predetermined cycle rate and using the PN clock source to
- 10 generate at least three PN component codes. Generating the PN component codes further includes the step of initializing a counter adapted to count the PN clock source cycles. The PN component codes are logically combined to produce a PN composite code. The next steps
- 15 provide an oscillatory reference source also with predetermined cycles and initializing a second counter adapted to count the cycles of the oscillatory reference source. The method also includes the step of determining a transmitter delta phase in accordance with counts from
- 20 the first counter and the second counter. The transmitter delta phase and the second counter count are PN composite encoded and transmitted at a predetermined rate, e.g., frame rate. At a receiver, the transmitted signal is partially correlated, from which recovered data a PN
- 25 composite code slip for chip aligning a receiver PN composite code with the transmitter PN composite code is determined.

- In accordance with another embodiment of the invention, a system for generating (PN) spread signals is provided.
- 30 The system includes a first clock and at least three pseudo-noise (PN) component code generators coupled to the first clock. A logic combiner coupled to the PN

component code generators is adapted to generate a composite PN code. In addition, a second clock is adapted to synchronize with the first clock, and both clocks are coupled to respective binary counters.

5 In accordance with another embodiment of the invention, an integrated circuit (IC) is provided. The integrated circuit includes a first clock and at least three first pseudo-noise (PN) component code generators coupled to the first clock. In addition, the IC includes a logic
10 combiner coupled to PN component code generators, and the logic combiner is adapted to generate a composite PN code. The IC also includes a second clock adapted to synchronize with the first clock, and both clocks are coupled to respective N-bit counters.

15 The invention is also directed towards a program storage device readable by a machine, tangibly embodying a program of instructions executable by the machine to perform method steps for generating and acquiring pseudo-noise (PN) composite spread signals. The method includes
20 the steps of providing a PN clock source having a predetermined cycle rate and using the PN clock source to generate at least three PN component codes which are logically combined to produce a PN composite code. The
25 method also includes initializing a first counter adapted to count the PN clock source cycles and providing an oscillatory reference source, the oscillatory reference source also having predetermined cycles. A second counter is adapted to count the cycles of the oscillatory
30 reference source. The next step determines a transmitter delta phase in accordance with counts from the first counter and the second counter and PN composite encodes

and transmits the transmitter delta phase and the second counter count at a predetermined rate, e.g., frame rate. At a receiver, the transmitted signal is partially correlated, and a PN composite code slip for chip aligning the receiver PN composite code with the transmitter PN composite code is determined.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the present invention are explained in the following description, taken in connection with the accompanying drawings, wherein:

Fig. 1A is a pictorial diagram of a communication system having a transceiver and PN code generator incorporating features of the present invention;

Fig. 1B is a block diagram of the receiver shown in Fig. 1A;

Fig. 2 is a block diagram of the master PN code generator shown in Fig. 1 incorporating features of the present invention;

Figs. 3A-3B is a pictorial representation showing one relationship between PN code chips, sample clocks per PN code chip, and elapsed time since PN initialization, respectively;

Fig. 4 is a method flow chart showing steps for one method implementing features of the present invention shown in Figs. 1A and 1B;

Fig. 5 is a block diagram of an alternative PN code generator incorporating features of the present invention;

5 Fig. 6 is a table illustrating time delay between requesting and receiving TSI for several representative waveforms;

Fig. 7 is a time graph representing the uncertainties of the representative waveforms shown in Fig. 6; and

10 Fig. 8 is a chip graph showing one grouping arrangement of the waveform uncertainties shown in Fig. 7 in order to search groups according to chip uncertainty.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

15 As disclosed herein, the present invention describes a novel method and system for PN code phase coordination and alignment of direct sequence spread spectrum signals.

Referring to Fig. 1A, there is shown a pictorial diagram of a communication system having a transceiver and PN code generator incorporating features of the present invention. Referring also to Fig. 1B, there is shown a block diagram of the receiver shown in Fig. 1. Although the present invention will be described with reference to the embodiments and examples shown in the drawings, it should be understood that the present invention could be embodied in many alternate forms of embodiments. For 20 example, it should be appreciated that the teachings herein may be applied to any group or assembly of spread spectrum (SS) receivers, including those that are fixed in place; vehicle mounted; and/or hand carried.

As shown in Fig. 1A, each mobile platform 1A1, 1A2, contains a correlator 1A5 and a PN code generator 1A3. Correlator 1A5 includes, as shown in Fig. 1B, a receiving system 1A6, a correlator 1B1, a link control processor (LCP) 1B21, and modulator/demodulator controller 1B22, PN subcomponent generators, 1B3-1B6, PN composite code generator 1B7 and a decision switch 1B8. In the preferred embodiment, a PN composite code generator generates a PN composite code according to logic arrangement shown in Fig. 2. It will be appreciated that PN code generator 1A3 could be used in place of PN subcomponent generators, 1B3-1B6, and PN composite code generator 1B7. However, for illustration and clarity, the block diagram is presented as shown but is not intended to be limited to this particular configuration. Still referring to Fig. 1, the demodulator 1B22 tests for X-code acquisition. When it has found X-code phase, its bus data controller alerts LCP 1B21. LCP 1B21 uses remote and local PN code phase data to calculate a slip command to demodulator 1B22. LCP 1B21 commands demodulator 1B22 slip to center of uncertainty; demodulator 1B22 then slips PN_c 1B7 through uncertainty in L_x steps.

In the preferred embodiment, the PN composite code is a PN decade-code and is constructed with four subcomponent PN codes logically combined as shown in Fig. 2. However, in alternate embodiments, any suitable number of subcomponent PN codes may be logically combined (Fig. 5). The PN decade-code, once started, spans a predetermined time span before repeating. In a preferred, but not limiting embodiment, the time span is on the order of years. In general the number of years is measured in decades.

As will be made clear, a data signal 29 (Fig. 2) that is spread by a PN decade-code constructed of four sub-component PN codes in accordance with the teachings of the invention can be despread and initially acquired by a receiver without full correlation of the entire PN spreading code.

Referring still to Fig. 2, in the preferred, but not limiting, embodiment, a spreading and despreading PN code is constructed of four subcomponent PN codes by PN subcomponent PN code generators 22-25. The outputs of the subcomponent PN code generators are MAND combined ($X \oplus (Y \text{ AND } (Z_1 \oplus Z_2))$), by logic devices 26, 27, and 28. In the preferred embodiment, the PN decade-code is designed to be substantially orthogonal with other PN codes. Also, in the preferred embodiment, one of the PN codes to the left of the AND in the MAND code is assigned to be an even-length code with special auto correlation properties. In alternate embodiments, any suitable number of component codes could be assigned to be a suitable length with suitable autocorrelation properties. For example, in alternate embodiments a suitable length code could be an odd maximal length code. In addition, a MAND composite code composed of four component codes in accordance with the teachings of the invention has partial correlation properties with its X, Y, and/or ($Z_1 \oplus Z_2$) component codes. For example, when a MAND code is mixed (or correlated) by a receiver (Fig. 1B) with an exact copy of its X code and the X code is aligned (in phase) with the MAND code, the MAND PN encoded data is recovered, albeit the recovered signal has $\frac{1}{4}$ the power than if full correlation were

achieved. Thus, by acquiring an even-length code first, in accordance with, but not limited to the teachings of the invention, symbol synchronization [of even or odd length] can be achieved independent of symbol synchronizers, and a partial correlation allows the recovery of encoded data from the received signal.

Acquisition of the four-component MAND PN code (PN decade-code) is accomplished by determining a PN code delta phase and time since initialization (TSI) of the transmitting and receiving PN decade-codes.

Referring also to Fig. 4, partial or x-code acquisition begins with receiving a data signal spread by the PN decade code, step 44. The PN spread data signal is correlated with the X-component code, chip-by-chip until the X-code partially correlates with the MAND PN coded signal. In the preferred embodiment, the x-component code is used for partial correlation. However, in alternate embodiments any suitable component code could be used. Correlation techniques are well known and need not be discussed here other than to note that when the X code is slipped one or $\frac{1}{2}$ chip, the Y, Z₁, and Z₂ component codes are slipped equally, step 46. In this manner, the entire composite code is slipped by one chip, preserving knowledge of the MAND PN component code phase.

Step 47 decodes the transmitter TSI and Delta phase, and steps 48, 49, and 401 determine an uncertainty range due to receiver TSI and slips or advances the MAND PN code in units of the PNx subcomponent code. It will be appreciated that time latencies associated with receiver

TSI (Fig. 6) and associated chip latencies may be predetermined and stored or determined as needed.

Steps 47-49 and 401 may be further explained by also referring Fig. 2, where it will be appreciated that each platform has an accurate method of keeping time since TSI of its respective PN generator in accordance with the teachings of the invention. In the preferred embodiment of the present invention each participating platform has a sampling clock 21 operating at rate R_{sc} sampling clocks per second (Sclk) and drives MAND PN code generation. In the preferred embodiment, the source of the sampling clock is a direct digital synthesizer (DDS) 21, and the DDS 21 generates its Sclk based on a digital seed word instruction. For explanation purposes, the digital seed word may be referred to as samp_rate, with units of DDS LSB's (Least Significant bits).

In the preferred embodiment, each modulator (transmitting platform) and correlator (receiving platform) has a sampling-clock counter 202, and each platform has its own reference clock 204, a 10 MHz reference oscillator, for example, and its own TSI counter 203. In the preferred embodiment, the TSI counter 203 is a 40-bit counter (or a counter of a number of bits that counts an unambiguous length of time--longer than the duration of the intended communication) that counts every cycle of a preferred 10 MHz reference oscillator. In alternate embodiments, the TSI counter 203 may be any suitable bit length counter, and the reference oscillator 204 may be any suitable reference oscillator. In addition, the reference oscillator 204 may be synthesized with the DDS and associated filters and multipliers 205-207 or a separate

dedicated DDS. As part of the initialization routine, sampling clock counter 202, TSI counter 203, PN generators 22-25, and DDS 21 are set or reset to zero by reset signal RESET₀. At this point, zero sampling clocks have been counted, zero reference clock cycles have been counted, and the PN code is at the beginning of its sequence (PN code phase equals zero). The relationship between samp_rate (DDS LSB's) and sampling rate (Hz) may be expressed as:

Equation 1

$$\text{samp_rate} = \frac{R_C \times \text{Sampling Clocks Per Chip} \times 2^{32}}{16 \times 6 \times ("10\text{MHz"} \text{ Reference Oscillator})}$$

In equation 1, the DDS sampling rate is expressed as the chipping rate (R_C) times the number of sampling clocks per chip (SCPC). The terms $2^{32} / 16 / 6 / 10 \text{ MHz}$ are shown as an example of how a digital synthesizer and frequency source can exploit a 10 MHz reference oscillator and multipliers and dividers in order to achieve a preferred chipping rate, and are not limiting. In alternate embodiments any suitable number and types of multipliers and dividers may be used. If the sampling rate were 100 MHz and if there were two cycles of the sampling clock per one chip (SCPC = 2), the chipping rate would be 50 Mc/s. For clarity, the values used in equation 1 can be reduced to a simpler form that is accurate only to the precision of an example 10 MHz reference oscillator:

Equation 2

$$\text{samp_rate} \equiv R_C \times \frac{2^{20}}{3 \times 5^7} \times \text{SCPC}$$

Referring also to Figs. 3A-3B, there is shown a sample relationship between chip rate R_C , sample clocks per chip SCPC, and TSI units. In the above 10 MHz reference example, a relationship between TSI and samp_rate may be defined as:

Equation 3

$$\text{TSI}_{\rightarrow \text{Chips}} = \text{TSI} (25.6 \mu\text{s LSBs}) \times \frac{2^8}{\text{"10 MHz"}} \times \frac{\text{samp_rate} \times 16 \times 6 \times \text{"10 MHz"}}{\text{SCPC} \times 2^{12}}$$

Thus converting a unit TSI to its equivalent number of chips, where, in this example, one TSI of a predetermined unit of 25.6 μs ($2^8 \times .1 \mu\text{s}$ cycles for a 10 MHz reference) is selected.

Which reduces to:

Equation 4

$$\text{TSI}_{25.6 \mu\text{s} \rightarrow \text{Chips}} = \text{TSI}_{25.6 \mu\text{s}} \times \frac{\text{samp_rate}}{\text{SCPC}} \times \frac{3}{2^{19}}$$

Equation 4 calculates the number of free-running chips that occurs within a TSI (with 25.6 μs LSB), where free running refers to the nominal samp_rate, and no Doppler, dither, clock correction, or intentional PN slips or advances are taken into consideration. In alternate embodiments, the TSI units can be any suitable units.

When DDS LSB's are added to or subtracted from a nominal `samp_rate`, the sampling clock rate increases or decreases, respectively, and accumulated delta phase ($\Delta\Sigma\theta$) results; this may occur with Doppler, dither, and clock correction. The symbol used for accumulated phase utilizes the Greek letters delta and theta ($\Delta\theta$), meaning difference in phase, and sigma (Σ), which is commonly used to represent accumulation, addition, or integration. Accumulated delta phase may be represented as follows:

Equation 5

$$\frac{\#SCLK}{SCPC} = TSI_{\rightarrow Chips} + \Delta\Sigma\theta$$

Equation 5 indicates that the number of sampling clocks (in terms of chips) counted from initialization is equal to the number of free-running sampling clocks that would have occurred during the stipulated TSI had only the nominal `samp_rate` been used plus the number of chips that occurred as a consequence of Doppler, dither, clock correction (any reason for which the `samp_rate` could have been increased or decreased). Intentional PN slips or advances may be denoted by $\Delta\theta_{XYZ1Z2}$, meaning that an intentional PN slip or advance is a delta phase (a deviation from the free-running, nominal PN code phase), and XYZ_1Z_2 indicates that composite code phase is involved (X, Y, Z₁, and Z₂ component code phases experience the identical phase shift). It can be seen that delta phase consists of component code phase plus accumulated phase, as follows:

Equation 6

$$\Delta\theta_{PN} = \Delta\Sigma\theta + \Delta\theta_{XYZ_1Z_2}$$

Equation 6 shows that delta phase consists of accumulated delta phase and component code delta phase. Positive delta phase represents a composite code phase advance, and a negative delta phase represents a composite code phase slip.

Equation 7, illustrates a time and phase relationship of the parameters that are used to determine composite code phase:

Equation 7

$$\theta_{PN} = \#SCLK \rightarrow Chips + \Delta\theta_{XYZ_1Z_2} = TSI \rightarrow Chips + \Delta\theta_{PN} = TSI \rightarrow Chips + \Delta\theta_{XYZ_1Z_2} + \Delta\Sigma\theta$$

Equation 7 shows that a PN code's composite phase is equal to the actual number of sampling clocks (whether they occurred at the nominal sampling rate or not, converted into chips) plus any intentional slips or advances (in chips), which equation is the same as time since initialization (converted into chips) plus delta phase (item 210 in Fig. 2) (in units of chips), which is substantially the same as time since initialization (converted into chips) plus component code delta phase and accumulated delta phase (both in units of chips). TSI and delta phase data are gathered at the same time. Stated differently, Equation 7 indicates that the PN composite code phase (θ_{PN}), the actual chip position within the entire PN code sequence from XYZ_1Z_2 epoch to XYZ_1Z_2 epoch, is equal to the number of free-running chips

($T_{SI} \rightarrow \text{Chips}$, TSI converted into chips) plus delta phase ($\Delta\theta_{PN}$), where TSI is an actual measure of reference oscillator clock cycles. Thus, determining a transmitting platform's composite code phase and a receiving platform's composite code phase, the receiving platform can calculate the phase difference between the two composite code phases and determine the amount by which the receiving platform's composite code phase needs to be slipped or advanced in order for its local MAND PN code to be in phase agreement with the transmitting platform's MAND PN code.

At this point in the acquisition, the receiving platform's correlator X code is in phase alignment with the received MAND PN code sequence. However, X-code-only alignment is a partial correlation; Y, Z₁, and Z₂ codes have not been aligned, and the correlated portion of the signal is substantially ¼ of the of the transmitted signal power. In order to achieve full correlation and full power, and full power the receiving platform aligns its Y, Z₁, and Z₂ codes (in addition to the X code) with the received PN sequence by slipping or advancing its Y, Z₁, and Z₂ component codes to the composite code phase of the received PN sequence.

The receiving platform then calculates the difference between its correlator PN code phase and the transmitting platform's reported modulator PN code phase (based on Equation 7) as follows:

Equation 8

$$PN_Code_Advance_Corr_Chips = \theta_PN_Modulator - \theta_PN_Correlator$$

Equation 9

$$\Delta\theta_{Corr} = TSI_{\rightarrow Chips_Mod} + \Delta\theta_{PN_Mod} - \{TSI_{\rightarrow Chips_Corr} + \Delta\theta_{PN_Corr}\}$$

Equation 10

$$\Delta\theta_{Corr} = TSI_{25.6\mu s_Mod} \times \frac{samp_rate}{SCPC} \times \frac{3}{2^{19}} - TSI_{25.6\mu s_Corr} \times \frac{samp_rate}{SCPC} \times \frac{3}{2^{19}} + \frac{\Delta\theta_{PN_Mod}}{SCPC} - \frac{\Delta\theta_{PN_Corr}}{SCPC}$$

Equation 8 and Equation 9 conceptually express the PN code phase advance needed by a receiving platform's correlator. Equation 10 is the form of the equation to be used by a receiving platform's Link Control Processor (LCP) 1B21.

A Modulator/Demodulator Controller (MDC, the microprocessor that controls PN generators, item 1B22 in Figure 1B) provides as status, in this example, possibly two versions of delta phase, either version of which may be used in Equation 10. One version, placed in close frame proximity to an instantaneous TSI, is the most current delta phase information, and is intended for acquisition purposes. The other version made available (tagged) once per XY epoch, is intended for range equation use, and can be chip latent on the order of 600 chips more latent than the most-current delta phase, for the example case being considered.

Relative to uncertainties being searched, a 600-chip latency is very small, allowing either version of delta phase to be used. Although it will be appreciated that either version of TSI may be used, instantaneous TSI is preferably used in Equation 10. TSI captured once per XY epoch (Tagged TSI) is potentially far too latent to be of

- any use for data-aided acquisition. The phase advance result of Equation 10 plus the result of Equation 14 is sent by the LCP 1B21 to the Modulator/Demodulator Controller (MDC) 1B22 by means of an operation command;
- 5 phase advance then positions the receiving platform's correlator code to the center of the uncertainty to be searched. Y , Z_1 , and Z_2 are also moved to the center of zero-phase uncertainty, step 49.
- 10 While the MDC 1B22 is in a data-aided acquisition wait state, waiting for its LCP 1B21 to command it to perform the necessary PN code phase slip on its receive PN code, the LCP calculates and sends an RX Slip every time it passes through an executive Loop (approximately 57 ms, as
- 15 an example). The MDC 1B22 keeps the most recent RX Slip value on erasable memory that may be overwritten with the most current slip value and may be purged upon entering any state that uses/consumes the RX Slip value.
- 20 In alternate embodiments, premature use of Equation 10 for a present search may result in PN code phase search in an inappropriate region of the composite code. Consequently, when the MDC 1B22 is in its data-aided search state (searching the area of PN code uncertainty
- 25 that its LCP commanded it to search), the LCP 1B21 may perform an RX slip overseer function; in other words, the LCP 1B21 may calculate and command RX slips, subsequent to an initial slip, if a predetermined condition is met; for example, if the following condition is met: $1 \times$
- 30 Equation 14 < Equation 10 < $-3 \times$ Equation 14, where Equation 14 represents the general solution, chip uncertainty being searched.

An RX slip (Equation 10) has been calculated, the result of Equation 14 has been added to it, the slip command (sum of the two) has been sent to the MDC 1B22, and the slip has been performed by the MDC 1B22. The zero phase position being sought should fall within the uncertainty being searched, step 48. Subsequent solutions to Equation 10 that are less than +1 times and more positive than -3 times the magnitude of Equation 14 preferably fall within the range of solutions that agrees with the current phase position of the receiver PN code. Solutions to Equation 10 that fall beyond this range may indicate that the receiver PN code phase position is in error, perhaps the result of inappropriate data, and a new slip command, based on the most current data, should be sent to the MDC 1B22.

Continuing, the MDC 1B22 preferably does not move its Y , Z_1 , and Z_2 component codes by the exact number of chips commanded by the LCP 1B21. It is desired that the MDC move its correlator PN code by a number of chips that results in its X code having the same phase as it has prior to the move, since the X-code is already partially correlated (in phase agreement) with the received signal. As noted above, Y , Z_1 , and Z_2 codes have been slipped with X, chip for chip. Therefore, each time X is slipped one chip, Y , Z_1 , and Z_2 are each slipped one chip, and $\Delta\theta_{XYZ1Z2}$ is decremented by one. Moving component codes Y , Z_1 , and Z_2 the same amounts preserves composite code phase, as expressed in Equation 7. Preferably, the MDC 1B22 checks that Y , Z_1 , and Z_2 component codes are moved a modulo X-length number of chips, thus maintaining X-code phase and moving to the nearest modulo X-code position commanded by

the LCP.) By using Equation 11, the MDC 1B22 insures that it moves its PN code by modulo X code length.

Equation 11

$$\Delta\theta_{\text{Corr}} = \Delta\theta_{\text{Corr}} - (\Delta\theta_{\text{Corr}} \text{ MOD } L_X)$$

Equation 10 calculates the PN code advance required to bring a receiver's locally generated PN code into phase agreement with the received PN code, based on TSI and delta phase information gathered locally and from the opposing platform. However, local and remote TSIs used in an LCP's calculation of Equation 10 are latent. The average time delay of TSI latency must be added (to the result of Equation 10) in order to advance the receiver's PN code position to the center of the uncertainty to be searched, and the one-sided uncertainty to be searched is half the distance between the maximum and minimum TSI delay. After a TSI arrives, the LCP must access it and compare it to its own TSI, using Equation 10. However, the receiving platform's TSI has to be gathered by the LCP 1B21 from the MDC 1B22, giving the receiving platform's TSI some latency by the time it is compared against the transmitting platform's TSI. Example budgets for TSI latency are shown in Fig. 6.

One example process (item) 5, referenced Fig. 6, deals with the "local" effort of getting TSI from the local MDC to the LCP: 9 ms for status and 0 to 70 ms for bus cycle time. TSI latency may be calculated in terms of PN code advance and uncertainty as follows:

Equation 12 Search Uncertainty

$$5 \quad \text{Search Uncertainty} = \frac{1x - 1n + 2x - 2n + 3x - 3n + Ax - An + 5lbc}{2}$$

Equation 13 PN Code Advance

$$\text{PN Code Advance} = \frac{1x + 1n + 2x + 2n + 3x + 3n + 3(Ax) + An + 2(B \text{ or } C \text{ or } D) - 2(5ls) - 5lbc}{2}$$

10

Equation 12 and Equation 13, x refers to maximum, and n refers to minimum. For example, $2x$ refers to the maximum value of line 2, which for Waveform A is 130 ms. Ax refers to the maximum value of equation A (line A of Figure 6). $5ls$ refers to line 5, Local Status, and $5lbc$ refers to line 5, Local Bus Cycle Time.

15

TSI time delays are graphically summarized in Fig. 7. Preferably, code alignment (zero PN code phase shift) exists within the uncertainty being searched, indicated by the double-headed lines (\leftrightarrow) of Figure 7. In alternate embodiments, -6 dB (representative of full correlation) correlations may exist at $\pm n \times L_{XY}$ (integer multiples XY lengths) from zero PN code phase shift and may be difficult to distinguish from zero phase shift correlations. Consequently, XY epochs from zero PN code phase shift are preferably avoided during acquisition in order to avoid false acquisition. Still referring to Fig. 7 there are shown example waveforms and their associated uncertainty ranges. It will be appreciated that only the

20

25

30

XY epochs for waveform C are shown in Fig. 7. The XY epochs for the other waveforms occur off the Fig. 7 scale and are not necessary here for purposes of explanation.

- 5 . As shown in Fig. 7, a general solution for most of the waveforms may be derived by including the shortest delay, which is rounded down to zero, and the longest delay, which is rounded up to 450 ms. The general solution PN code advance is then 225 ms ($450 \div 2$), and the general solution PN code uncertainty to be searched (center to edge) is 225 ms.

Equation 14 General Solution to Data-aided YZ PN Code Advance and Uncertainty:

$$15 \quad \text{PN Code Advance (or uncertainty)} = 225 \text{ msec} \times \frac{\text{samp_rate}}{\text{SCPC}} \times \frac{3 \times 5^7}{2^{20}}$$

- In alternate embodiments where waveform uncertainty ranges approach the XY epoch it may be desirable to have more than one general solution or a solution for each uncertainty range. For example, if Waveform C (Fig. 7) were included in the general solution example above, use of the shortest delay by Waveform C would take its modified uncertainty range closer to its nearest XY epoch, and use of the longest delay caused by Waveform C may add too much overhead to the general solution. Thus, for Waveform C, the 225 ms of Equation 14 should be substituted with 297 ms and 191 ms for PN code advance and uncertainty, respectively.

- 30 Referring also to Fig. 8, there is shown a graphical summary, in terms of chips, the effect of using a general solution to advance and search an uncertainty. It can be

seen that a general solution searches more of a PN code sequence than uncertainty budgets indicate are necessary. It will be appreciated that the advantage of a general solution is the resulting system and hardware simplification.

Returning to Fig. 4, the local platform's LCP 1B21 has collected TSI and delta phase information from the opposing (transmitting) platform, step 47. Similarly, the local platform's LCP 1B21 has collected TSI and delta phase information from its own MDC 1B22 and has used that data to calculate the composite PN code phase of its locally generated PN code, step 404, the one being compared to the received signal.

The local platform's LCP 1B21 subtracts its composite code phase from the opposing platform's composite code phase (Equation 10). As noted above, this difference does not take into account the uncertainties of the data used to make the calculation.

Because the opposing platform's TSI data represents information that may be delayed (see Fig. 6), the opposing platform's composite code phase may be more progressed (advanced) in phase than reported by its TSI. Based on the example shown above, the local platform should advance its composite code phase by as little as 0 seconds or as much as 450 milliseconds.

In accordance with the teachings of the present invention the local LCP 1B21 moves its composite PN code to the same composite PN code phase position as reported by opposing platform (the difference determined by Equation

10). The local LCP 1B21 advances its local copy of its correlator (receiver) PN code if the [Equation 10] difference is positive and slips it by the difference if the difference is negative. In addition, the local LCP

5 1B21 adds the maximum advance needed to compensate for worst-case TSI latency combinations. Thus, twice the value of Equation 14 may be added to the value of Equation 10 to equal the number of chips to be slipped (if the result is negative) or advanced (if the result is

10 positive) that places, steps 48-49, the local platform's PN code at the most-advanced-phase boundary of the uncertainty to be searched. Only the X code of local platform's PN code is zero-phase aligned with the PN code received from the opposing platform. (It is due to the

15 partial correlation of this alignment that the local platform is able to recover data from the received data stream.) In order for the local LCP to maintain this X-code, zero-phase alignment, the local platform preferably changes its PN code phase (move its PN code) by a modulo-

20 X-length number of chips. The LCP 1B21 commands the MDC 1B22 to move the given number of chips (Equation 10 plus Equation 14), and the MDC 1B22 modifies this number, using Equation 11, forcing the number of chips to move to be an exact X-code-length number of chips, step 401.

25

The MDC 1B22 moves the entire PN code to the most-advanced-phase position of the uncertainty to be searched, step 49. In alternate embodiments more than one correlator may be used and the PN code may be moved to a

30 position other than the most advanced position. For example, in an embodiment having two correlators, one correlator starts at the center and slips to the end of the uncertainty, while the 2nd correlator starts at the

middle-plus-advance-by-1/2-the uncertainty and slips/searches to the center. Returning to the present example, the uncertainty to be searched, using the results of the example's uncertainty, is 450 milliseconds long. If the chipping rate were 325 Mc/s and the X-code length were 2^{13} , 8192 chips, the uncertainty to be searched would be 146,251,776 chips (450 ms \times 325 Mc/s + 1776 [for modulo X length]). There are 17,854 X epochs within this uncertainty. The MDC, in effect, slips its composite PN code in X-length increments, testing for correlation at the Y, Z₁, and Z₂ component code phases at each of these X-epoch positions, testing for full correlation (composite, zero phase alignment), step 402. It will be appreciated, in terms of the example shown, that rapid acquisition is achieved by searching the uncertainty of 146 Mchips with only 17.8 K tests. Stated differently, only 17,854 phase positions are tested in an uncertainty of 146,000,000 chips.

It is appreciated that the PN-decade codes described herein provide unambiguous PN code phase throughout calendar decades and allows DSSS communication systems to join or rejoin a particular communication network operating with a PN-decade code. In a preferred embodiment, the DSSS communication systems operating with PN-decade codes are collocated with naval platforms (ships, aircraft, etc) and advantageously allow the platforms to join and communicate with a fleet at any time, with unambiguous time and unambiguous PN code phase alignment.

It will also be appreciated that the advantageous use of four component codes allows for high chipping rates and

pseudo-noise (PN) code lengths that repeat themselves at intervals that exceed calendar decades. The method obviates repeatable schedules of PN code phase versus time within an hour or time of day or time of week, et cetera.

It is also appreciated that platform communication systems operating with the PN-decade codes described herein can arrive at an already assembled fleet of platforms and resolve spatial uncertainties without time ambiguities or calendar ambiguities. Advantageously, a fleet, or components of the fleet, may assemble at any desired time without time or calendar ambiguities and without having to reset all fleet participants to a common clock reference; and no ambiguous register rollovers exist.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. For example, in alternate embodiments, any suitable method (Fig. 5, item 58) for combining component codes may be used; MAJ combined codes may be used in place of MAND combined codes. MAJ for a 4-component-code sequence:

$$XYZ_1Z_2: \text{MAJ} = (X \bullet Y) \oplus (X \bullet Z_1) \oplus (X \bullet Z_2) \oplus (Y \bullet Z_1) \oplus (Y \bullet Z_2) \oplus (Z_1 \bullet Z_2)$$

In addition, in alternate embodiments any suitable number of component codes may be used. Referring to Fig. 5 there is shown one such possible alternative embodiment. It will be appreciated that items 51-58 can be individual

components or an integrated circuit (IC), item 59. It will be further appreciated that the IC may be a field programmable gate array (FPGA) or an application specific IC (ASIC), which the operation of either may be defined by a suitable programming language such as a Very High Speed Integrated Circuit (VHSIC) Hardware Description (VHDL) Language file. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances that fall within the scope of the appended claims.